BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

As rescanning documents *will not* correct images, please do not report the images to the Image Problem Mailbox.

1 496 837

PATENT SPECIFICATION

(11) 1 496 837

(21) Application No. 47695/75 (22) Filed 19 Nov. 1975
(31) Convention Application No. 49/133810
(32) Filed 20 Nov. 1974 in
(33) Japan (JP)
(44) Complete Specification published 5 Jan. 1978
(51) INT CL² G01R 23/00
(52) Index at acceptance
G1U 10X12 6

(19)

(54) METHOD AND APPARATUS FOR MEASURING THE FREQUENCY AND/OR PERIOD OF A SIGNAL

(71) We, YOKOGAWA - HEWLETT-PACKARD, LTD., a Japanese Company of 9-1, Takakura-cho, Hachioji-shi, Tokyo 192, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention is related to a method and an apparatus for measuring the period duration and/or frequency of a substantially periodic signal having random components.

Such signals appear in many areas of technology and science. Especially periodic signals coming from biological systems, e.g. signals derived from the human heart beat are usually only approximately periodical and have a waveform changing from period to period.

A special problem of the medical measuring technique is monitoring of the heart activity of a fetus before or during delivery. Four relevant measuring methods are known for this purpose, namely direct ECG, abdominal ECG, acoustic sound measurement and ultrasonic doppler measurement. The best results are provided by the direct ECG which method simultaneously requires only small signal processing efforts. In this case, however, an electrode must be connected to the head of the child which is not easy to do and cannot be done by clinical clerks.

The ultrasonic measurement, on the other hand, can easily be performed by untrained people and provides valuable information about the heart activity. The drawback of this method is that the obtained signal has several components of different frequency ranges which make it difficult to detect the exact basic period duration. However, the exact measurement of the basic period duration is necessary since the instantaneous heart rate can be derived from this period duration. The ultrasonic signal has substantially three components, namely the blood flow signal (frequency range below 500 Hz), the valve signal (frequency range 400—1000 Hz), and the muscle signal (frequency range 150—400 Hz). These frequency ranges are the doppler shifts at an ultrasonic frequency of 2.1 MHz. The blood flow signal and the muscle signal have very rough envelopes and therefore are not suited for obtaining trigger points. The valve signal is, in view of its shape, better suited for deriving trigger points. For this purpose the ultrasonic signal must be suitably filtered and rectified for getting the envelope waveform.

However, difficulties arise also in this case since the heart has different valves and each of these valves closes and opens during a heart beat period. Additionally movements of the fetus cause shape and amplitude changes of the signal.

It is known to determine the period duration of complicatedly shaped signals or of signals disturbed by noise by means of cross correlation methods. In these cases the signal to be measured is cross correlated with a known waveform which is supposed to have a similar shape as the signal to be measured. The distance in time between the maximum peaks of the resulting cross correlation waveform is a measure for the period duration and frequency, respectively, of the signal to be measured. Known cross correlation methods require a relatively exact knowledge of the periodical component of the signal to be measured for providing a suitable reference signal. This is not difficult if the signal to be measured is known in its original shape, e.g. as transmitted signal of a radar equipment.

This is not valid for biological signals. Moreover, frequency and shape of such signals vary from time to time.

By making use of the present invention it is possible to measure the period, duration and/or frequency of a signal employing a cross correlation method but not requiring

an exact knowledge of the original shape of the signal to be measured.

The method according to the present invention comprises the steps of periodically storing successive sections which may overlap of the signal to be measured in a first memory; storing a reference signal of the same length as each said section in a second memory; periodically cross correlating said sections of the signal to be measured and said reference signal; producing a pulse for each relevant peak of the cross correlation waveform; deriving the period and/or the frequency of said signal to be measured from said pulses; and periodically updating the contents of the second memory in accordance with the actual signal sections received in such a way that the reference signal approaches the form that the periodic signal would have in the absence of said random components.

The apparatus according to the present invention comprises first memory means for storing successive sections of the signal waveform to be measured; second memory means for storing a reference waveform of the same length as each said section; cross correlator means for repeatedly cross correlating said sections of the signal waveform and said reference waveform; peak detecting means for producing a pulse corresponding to each of the relevant peaks of the cross correlation waveform; processing means for deriving the period and/or the frequency of said signal waveform from said pulses; and updating means for periodically updating the contents of the second memory in accordance with the actual sections of the signal waveform received.

A particular embodiment of the invention is now described by way of example with reference to the accompanying drawings in which:—

Figure 1 is a general block diagram of a preferred embodiment of this invention;

Figure 2 is a circuit diagram of the peak detector, included in Figure 1; and

Figure 3 shows waveforms for illustrating different seed patterns.

Referring now to Figure 1 A-D converter 11 samples the analog signal at input 10 with 400 Hz and converts the samples into digital 4 bit 2's complement fixed and signed binary expressions. The following processings are all done by such a signal, fixed 2's complement binary expression which is transferred parallel in every stage.

The output signal of A-D converter 11 is fed into a shift register 15 through a recirculation control logic 13. The shift register 15 has a storage capacity of 256 words with 4 bits per word. Together with an additional one word register 17 a recirculating loop 18 for 257 words is provided. This loop is driven by a 102.4 kHz clock and operates so that it dispos s the oldest data word and enters a new word every recirculation period of 2.5 msec (corresponding to 400 Hz). The shift register 15 keeps at any time the data from the actual time till 640 msec ago. One can observe every data word, once within one recirculation period, at any fixed point of the shift register 15.

These recirculating data are simultaneously fed into a multiplier 19, and also into a circulating intermediate memory 24 comprising a shift register 23 and a recirculation control logic 21. The intermediate memory 24 recirculates once per 2.5 msec. It is described in more detail below.

The multiplier 19 is an asynchronous parallel multiplier. The other input of this multiplier is connected to a third calculating memory 30 comprising a shift register 29, a first adder 27, and a recirculation control logic 25. This third recirculating memory keeps the reference waveform. It will be described in more detail below.

Thus, the multiplier 19 gets two input signals, one of which is the latest data set of the input waveform and the other of which is the reference waveform. The multiplier 19 continuously produces products of the contents of the corresponding locations of registers 15 and 29 at the clock frequency of 102.4 kHz according to the equation

$$P(k)=D(k) \cdot S(k) \qquad (1)$$

where k means the logical address (o — 255) of both registers 15 and 29 respectively, P means the product, D means the reference data and S means the sample data.

The output data of said multiplier 19 is summed up by a second adder 33 and a buffer register 35, resulting in a sum of 256 products per recirculation period (2.5 msec).

Thus

$$C(t)=\sum_{k=0}^{255} P(k)=\sum_{k=0}^{255} D(k) \cdot S(k) \qquad (2)$$

is stored into the said buffer register 35, and this means, although without normalization, a cross correlation value of the contents of both registers 15 and 29. At each end of a 2.5 msec period, this cross correlation value is transferred into an output buffer register 37. The contents of this buffer register 37 is, in digital form, the cross correlation waveform which has peak values at those points where sample waveform and reference waveform have

generally the same shape. The distance in time between these peak values is the period duration of the input signal in real time. The cross correlation output is fed into a peak detector 40, via a D-A converter 39.

The details of peak detector 40 are shown in Figure 2. The cross correlation signal coming from said D-A converter 39, is fed via input terminal 401 into a rounding low pass filter 403. This low pass filter 403 has a cut off frequency of about 100 Hz, to smooth and interpolate the stepping shape output waveform of said D-A converter 39.

Operational amplifiers 405 and 407, diodes D_1 and D_2 and capacitor 409 form a peak holder and peak detector for the smoothed output signal of said low pass filter 403. The capacitor 409 is charged according to the upgoing slope of the input signal of said amplifier 405, but does not follow the down going slope of said signal because of existence of the diodes D_1 and D_2. The voltage at capacitor 409 is kept just at the same voltage as the peak voltage of said input signal of said amplifier 405, because of the exact feedback by amplifier 407. The charge current of said capacitor 409 is detected by amplifier 411, and in this charge sequence a transistor 413 is kept to be "on", and a capacitor C1 is discharged to zero voltage.

After the charge sequence has been terminated, the transistor 413 turns off and a timer 420 including an amplifier 419 begins its timing sequence. Capacitor C1 is charged to a certain threshold voltage where the amplifier 419 turns its output signal which also causes a field effect transistor 421 to turn on, and this results in that said holding capacitor 409 is discharged to a certain voltage determined by a zener diode ZD. The circuit then waits for the next peak. The end of said charge sequence corresponds to the peak location of the cross correlation waveform on the real time axis, with a certain time delay, suppose 250 msec. This delay of 250 msec is shorter than the shortest period of fetal heart movement which is about 285 msec. If another peak, greater than the preceding peak, is met during the delay period, capacitor 409 is charged, capacitor C_1 is discharged, and after reaching the peak voltage of capacitor 409 a new delay period is started. Thus, only the greatest peak values become significant. The turning of said amplifier 419 is transmitted via transistor 423 to a gate 427, and finally given to an output terminal 431 as trigger pulses to drive a suitable rate meter.

The amplifier 411 is connected via transistor 417 to a further gate 425 which, at terminal 429 gives a copy command having one logic state when the holding capacitor 409 is being charged-up, and having another logic state during the remaining time. The signal from output 429 is fed to the recirculating control logic of intermediate memory 24 (Figure 1) as indicated by the upper dotted line in Figure 1. When the copy signal has its one logic state, intermediate memory 24 is connected to circulating loop 18 in such a manner, that its contents are copied into the intermediate memory 24.

Copying is interrupted after terminating the charge sequence, which means a probable peak location. This causes register 23 to connect its entrance to its own exit, and to disconnect the intermediate memory 24 from the signal input. The intermediate memory 24 then keeps its contents unchanged and circulates at the same rate as loops 18 and 30. But if again the charge sequence appears, which means that there appeared another higher peak, the intermediate memory disposes its content and again copies the shift register 15 until the new peak maximum is reached. When no more peak has appeared within said delay period of 250 msec, the latest peak must be the true peak which corresponds to the highest analogy between input waveform and reference waveform. Thus the memory 24 always gets the most actual reference waveform.

Refreshing of the contents of loop 30 is done as follows: In the circulating memory loop 30, the input of shift register 29 is connected to the output of said first adder 27, one of the two input terminals of which is connected to the output of shift register 29, and the other is connected to the output of recirculation logic 25, which, in turn, receives the output signals of shift register 29 and intermediate memory 24. Adder 29 sums its two input signals 271 and 273 and divides the sum by two; in the present example by dropping the least significant binary bit.

In ordinary condition adder 27 accepts two identical input signals coming from the output of the shift register 29. So the output signal of this adder is twice of this input signal, divided by two so that the recirculating memory loop 30 keeps its content unchanged.

Upon a pulse appearing at output 431 (Figure 2) and fed via AND-gate 45 (Figure 1) to recirculation logic 25, this logic disconnects the output of shift register 29 from adder input 271 and connects this input to intermediate memory 24. The pulse at output 431 (Figure 2) is 2.5 msec wide, which is just one recirculation period where the intermediate memory 24 is connected to

adder input 271. The following operation is done for each data word:

$$D(n+1,k)=1/2\{D(n,k)+I(n,k)\} \quad (3)$$

Here D(n+1, k) is the newly refreshed reference value, D(n,k) is the old reference value and I(n,k) is the data word in the intermediate memory 24, n is the recirculation number and k is the local address of the registers.

The AND-Gate 45 is used to inhibit this operation when the refreshment must not be done for some reason. At the beginning of a measurement the shift register 29 is empty. Thus, the cross correlation could not be calculated, and also no peak would appear, the peak detector would not give any trigger and refresh command, and there would be no possibility to let the register 29 acquire a reference waveform. This means that this system cannot start without any seed waveform in the register 29.

As shown in Figure 1, for this purpose, a seed pattern memory 31 is used. At the initial starting of measurement the seed pattern memory 31 sends a seed pattern into the third input terminal of said recirculation logic 25 and thus into loop 30 for one or more periods of recirculation. The dotted control line through OR-Gate 43 is the respective command line.

The seed pattern may theoretically be any waveform different from zero or some constant, however, preferably is selected to have some analogy to the measured signal waveform for facilitating adaption of the reference waveform. For example, a reference waveform shown in Figure 3b is not favourable for correlating a signal waveform as shown in Figure 3a. It is most favourable when the dominant characteristic part of the reference waveform is located in the center part of the shift register 29 as shown in Figure 3c. Simplified but also suitable seed patterns are shown in Figure 3d and 3e. Waveforms as shown in Figure 3g or 3h are not favourable since their signal energy is too small and also dislocated waveforms as shown in Figure 3f, are not favourable.

The initialization might be needed not only when starting this system, but also when the input signal has got too weak or some noise has disturbed the ordinary conditions. New introduction of the seed pattern is then performed by a pulse fed through an OR-Gate 43 and the following control line.

The reference waveform in loop 30 (Figure 1) may be subject to a certain phase drift. For compensating this drift said seed pattern might be used for phase comparation with the reference waveform and correction of its phase. This might be done automatically.

Since the systolic and diastolic sequence of a fetal heart does not exceed 500 msec, the effective length of shift register 15 here used (640 msec) is quite enough for a full period of the incoming signal waveform.

However it is not necessary to make the shift register 15 long enough for the full period of the incoming signal waveform. It is sufficient if only a relatively high amplitude part of this waveform is stored, especially if the above mentioned phase control is provided.

In order to store only a relatively high amplitude part, the circuit could include gating means so that only the high amplitude part passes to the shift register 15.

WHAT WE CLAIM IS:—

1. A method for measuring the period and/or the frequency of a substantially periodic signal having random components, said method comprising the steps of: periodically storing successive sections which may overlap of the signal to be measured in a first memory; storing a reference signal of the same length as each said section in a second memory; periodically cross correlating said sections of the signal to be measured and said reference signal; producing a pulse for each relevant peak of the cross correlation waveform; deriving the period and/or the frequency of said signal to be measured from said pulses; and periodically updating the contents of the second memory in accordance with the actual signal sections received in such a way that the reference signal approaches the form that the periodic signal would have in the absence of said random components.

2. A method according to Claim 1, wherein the step of periodically updating the contents of the second memory comprises the steps of: storing said sections of the signal to be measured in a third memory; periodically fetching the contents of said third memory; and deriving an updated reference signal waveform from said fetched waveform.

3. A method according to Claim 2, wherein the step of deriving an updated reference waveform comprises the step of adding a predetermined fraction of the amplitude of the previous reference waveform and a predetermined fraction of the amplitude of the fetched signal waveform.

4. A method according to Claim 1, 2 or 3 comprising the additional step of generating an arbitrary reference waveform at the beginning of the measur ment said arbitrary reference waveform having

roughly the shape of the expected signal waveform to be measured.

5. A method according to Claim 1, wherein the amplitude of the signal to be measured is small over a first part of the signal period compared with the amplitude of a second part during said period comprising the additional step of gating said signal to be measured so that only said second part of each period is cross correlated with said reference waveform.

6. An apparatus for measuring the period and/or frequency of a substantially periodic signal having random components, comprising in combination: first memory means for storing successive sections of the signal waveform to be measured; second memory means for storing a reference waveform of the same length as each said section; cross correlator means for repeatedly cross correlating said sections of the signal waveform and said reference waveform; peak detecting means for producing a pulse corresponding to each of the relevant peaks of the cross correlation waveform; processing means for deriving the period and/or the frequency of said signal waveform from said pulses; and updating means for periodically updating the contents of the second memory in accordance with the actual sections of the signal waveform received.

7. Apparatus according to Claim 6, comprising third memory means for periodically storing sections of the signal waveform, and control means for fetching said sections of the signal waveform from said third memory means and for deriving an updated reference waveform from said fetched section of the signal waveform.

8. Apparatus according to Claim 7, comprising adding and multiplying means for adding a predetermined fraction of the amplitude of the reference waveform and a predetermined fraction of the fetched section of the signal waveform.

9. Apparatus according to Claim 6, 7 or 8, wherein fourth memory means is provided or storing an arbitrary reference waveform and wherein said control means is capable of transferring said arbitrary reference waveform from said fourth memory means to said second memory means at the beginning of each measurement.

10. Apparatus according to Claim 6, comprising gating means for gating said signal waveform so that only preselected sections of each period of said waveform are allowed to pass into said first memory means.

11. A measuring method substantially as herein described with reference to the accompanying drawings.

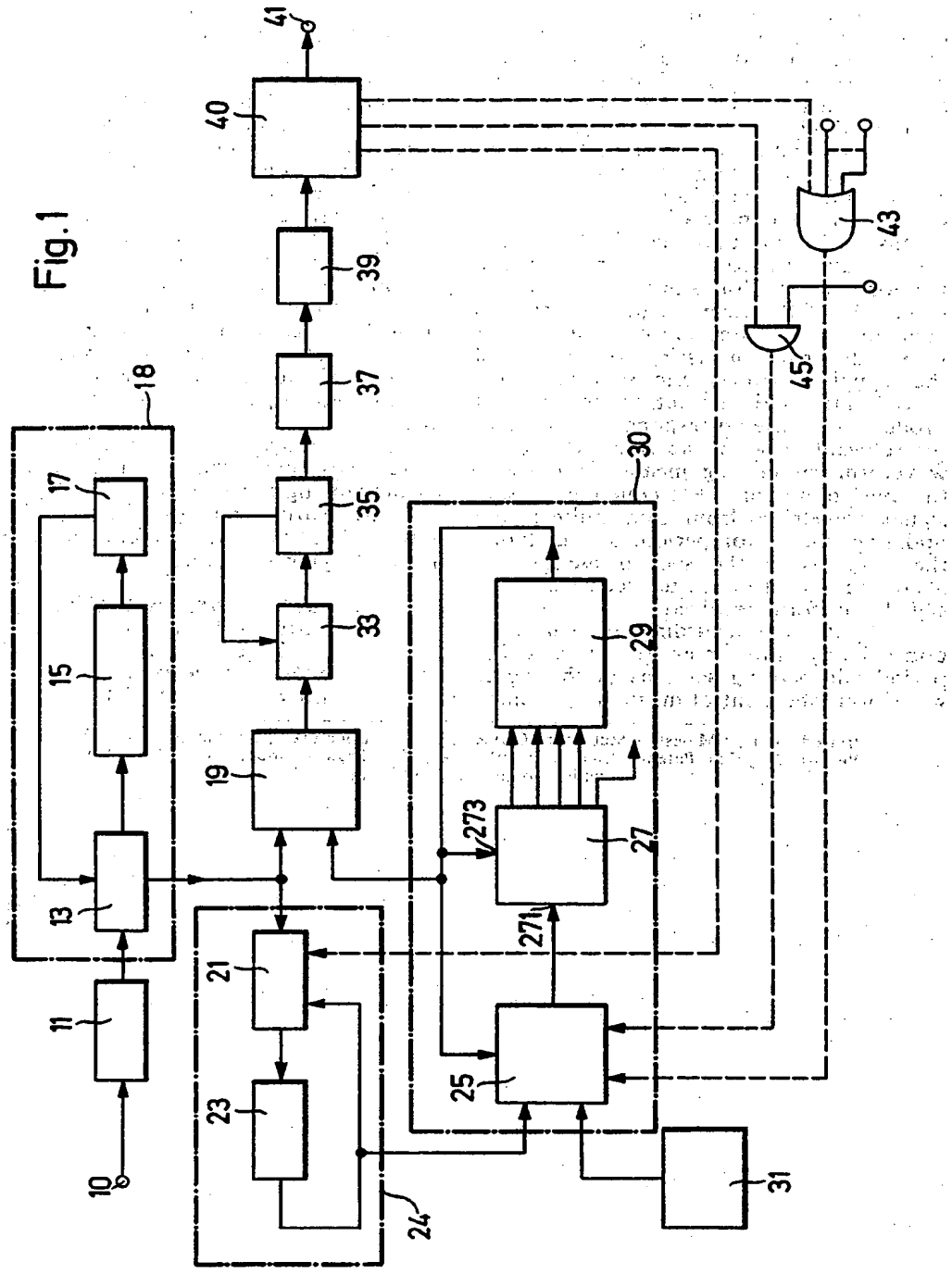
12. Measuring apparatus substantially as herein described with reference to the accompanying drawings.

R. G. C. JENKINS & CO.,
Chartered Patent Agents,
Chancery House,
53/64 Chancery Lane,
London, WC2A 1QU.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1978
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1 496 837
3 SHEETS
COMPLETE SPECIFICATION
This drawing is a reproduction of the Original on a reduced scale.
SHEET 1

Fig.1



1 496 837 COMPLETE SPECIFICATION
3 SHEETS

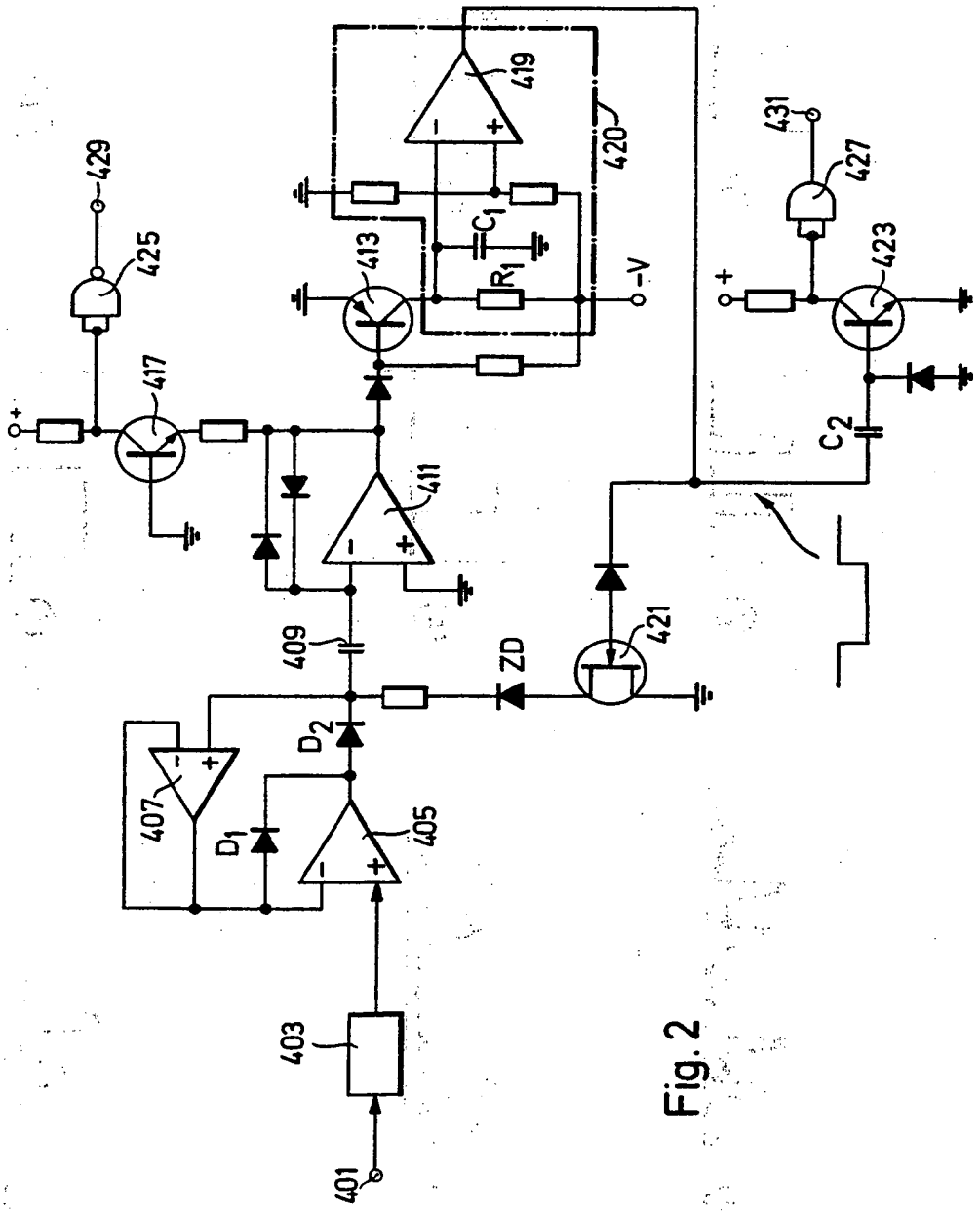


Fig. 2

1 496 837
3 SHEETS

COMPLETE SPECIFICATION

This drawing is a reproduction of the Original on a reduced scale.
SHEET 3

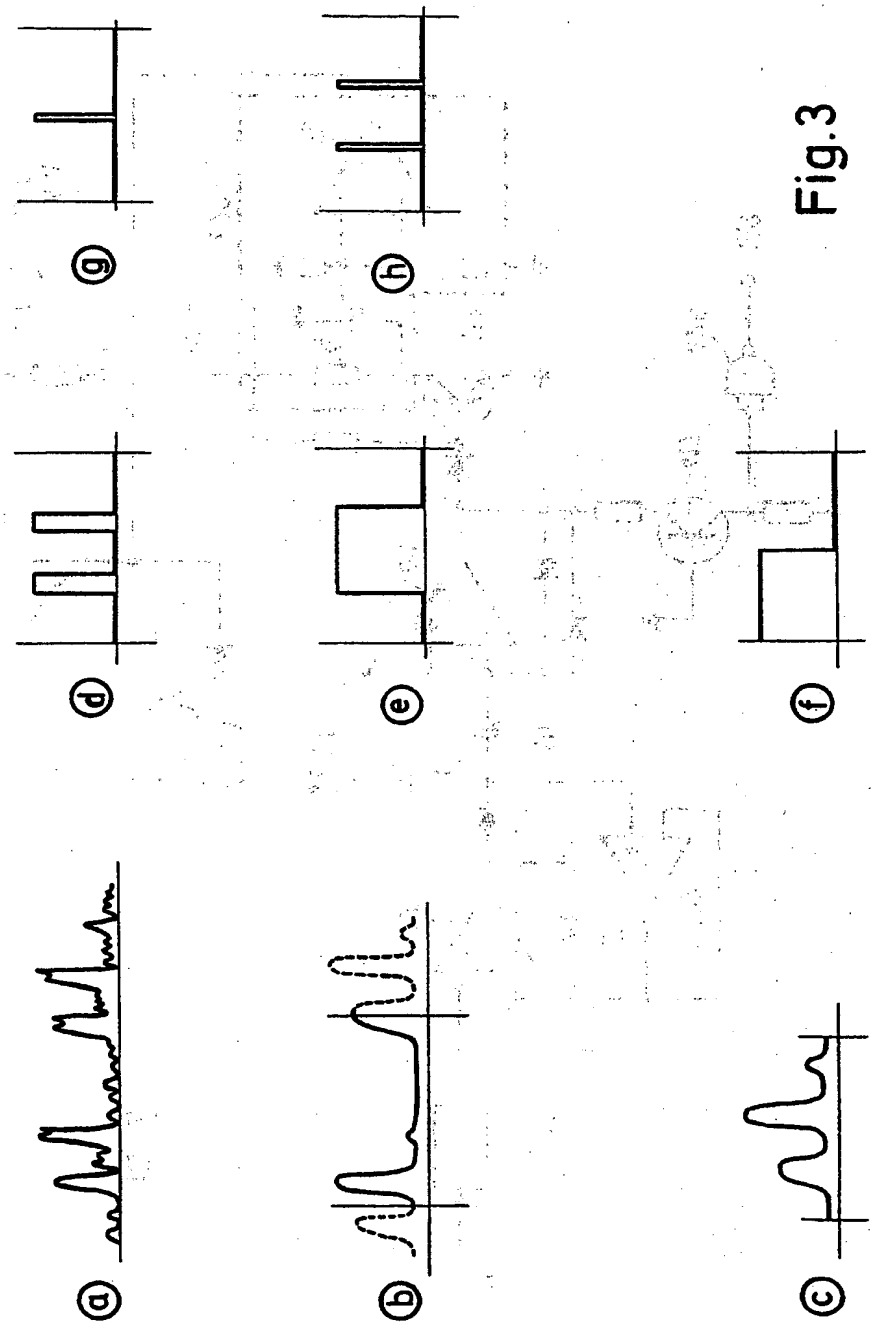


Fig.3